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CARBON RESISTORS FOR CRYOGENIC LIQUID LEVEL MEASUREMENT

RICHARD C. MUHLENHAUPT AND PETER SMELSER

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Richard Muhlenhaupt and Peter Smelser

Data are shown in graphical form. One set of plots presents resistance ratio R_G/R_L as a function of "warming up" time at various levels of constant power dissipation. A second set of plots presents resistance ratio R_L/R_O as a function of nominal resistance at various levels of constant power dissipation.

The use of the data and the design of a practical liquid level inidcator are discussed in the appendix.

1. Introduction

In the past few years sufficient interest has been shown in the use of ordinary carbon composition resistors for cryogenic liquid level measurement to warrant a study of the various parameters involved in the design of this type of liquid level indicator. Resistors are commonly used for the detection of liquid levels when a simple and inexpensive point sensor is desired and when precise indication and fast time response are not critical requirements.

The principal of operation is based upon (1) the heat transfer characteristics of the resistor in gas and liquid, and (2) the large negative temperature coefficient of resistance which occurs when the resistor is in a cryogenic environment.

The circuitry required for the detection of liquid levels by this method includes a Wheatstone bridge (the liquid level resistor being one of the arms), a power supply, an amplifier, and the desired readout equipment (lightbulb, galvanometer, relay, etc.).

When a liquid level indicator is to be designed, the following three parameters should be known: the maximum allowable power dissipation, the temperature of the liquid to be detected, and the desired response time (determined by the vaporization rate and the allowable liquid level drop). If data relating these parameters to design criteria were available, the design of functional liquid level indicators would be facilitated.

Accordingly, tests in liquid nitrogen, hydrogen, and helium were conducted on a number of 0.1 watt (manufactured by Ohmite) and 0.5 watt (from general stock, manufacturer unknown) carbon composition resistors having nominal resistances ranging from 10 to 10,000 ohms. Carbon deposited film 1% resistors were also included in the test program; these, however, were found to be relatively insensitive to extreme temperature reductions (see figure 1) and are not recommended for liquid level measurement.

The test program is discussed in the following pages, and the results are shown in the accompanying graphs. In addition, some observations regarding resistor precision and reliability are noted.

2. Description Of Test Apparatus

The test apparatus consisted of two major units: the probe assembly and the associated electrical circuitry. Principal components of the probe assembly are shown in figure 2. The guide tube houses a moveable plunger tube which in turn supports the test resistor. An adjustable stop controls the positioning of the test resistor in relation to the liquid-vapor interface, the location of which is determined by the liquid level sensor fastened to the end of the guide tube. A microswitch, actuated when the resistor is passing through the liquid-vapor interface, provides a zero time signal.

The electrical circuitry is shown in figure 3. A 60 watt, D. C., constant voltage, power supply provides the necessary power. Resistors R_1, R_2, R_3, and either R_T or R_C form a Wheatstone bridge. Decade box R_3 is used to balance the bridge when the test resistor is in the circuit, and decade box R_C (checking resistor) is used to determine the resistance of R_T and to calibrate the recorder. A recorder charts the bridge unbalance as the resistor passes through the liquid-vapor interface. A potentiometer is used to measure the voltage drop across the bridge.

3. Experimental Procedure

Twelve 0.1 watt and twelve 0.5 watt carbon composition resistors were tested. For each power rating, three resistors of each value (10, 100, 1000, and 10,000 ohms) were chosen. After the selected resistor was attached to the leads on the plunger tube, its room temperature resistance (R_O in figures 13 and 14) was measured with a Wheatstone bridge. Then the travel of the plunger tube was adjusted to permit moving the test resistor from a submerged position to a point slightly above the liquid-vapor interface.

With the sensor in the submerged position, the magnitude of the resistance in liquid (R_L in figures 4 through 12) was determined by balancing the bridge, substituting checking resistor R_C, and adjusting the resistance of R_C equal to that of R_L. A resistance calibration was established by adjusting R_C (while in the circuit) to a number or predetermined resistance levels and recording the resulting recorder deflections.

The actual testing was begun with the test resistor submerged in the liquid bath. The recorder chart drive was turned on, and the plunger tube was quickly raised causing the microswitch to be actuated, which

momentarily placed a resistance in parallel with R_T for the zero time indication. When a resistance change of about 5% had been reached, the chart drive was turned off. During this process, the voltage across the bridge was measured with the potentiometer.

This procedure was repeated three times at approximately the same bridge supply voltage. The supply voltage was then changed to provide a new power level and testing was resumed. When tests had been conducted at three or four different voltage settings, a new resistor was selected and the process repeated.

4. Discussion of Results

The data obtained from the test program were plotted in the form of curves which are presented in figures 4 through 14. Each of the first nine graphs (figures 4 through 12) show resistance ratio (R_G/R_L) as a function of "warming up" time at various levels of power dissipation.

The plots show that level indicating sensitivity improves with increased power dissipation. They also show that sensitivity is increased when the temperature of the resistor's environment is lowered (i. e., sensitivity is best in helium, next best in hydrogen, and poorest in nitrogen).

It was expected that the ratio R_G/R_L in the time response curves would begin at unity and continuously approach some lower value; however, for most plots this is not the case. Instead, the ratio becomes larger than unity before dropping to lower values. This suggests that the resistor, after passing through the liquid-vapor interface, senses a lower temperature. At the present time no satisfactory explanation of this behavior has been worked out.

In order to avoid this initial "negative" effect, it is suggested that a resistance ratio of 0.98 (an arbitrary figure that may be adjusted to the designer's requirements) be used as the time response determining

figure.

It should be noted that: (1) the test conditions could not be identically reproduced for resistors of the same nominal rating, and (2) much of the data was combined in order to reduce the number of final graphs. The plots represent average data derived from three individual runs for each test condition. In addition, the only 10 ohm resistors which gave reasonable response times were those having 0.1 watt nominal rating, and furthermore these gave usable results only when used in helium. Although deviations were observed, it was felt that they were insufficient to impair the usability of the curves.

The final two graphs (figures 13 and 14) show resistance ratio as a function of nominal resistance for several series of resistors operated at various power levels. On these graphs the resistance ratio is the measured resistance in liquid (R_L) divided by the measured resistance at room temperature (R_O), while the abscissas of the graphs represent the nominal resistance rating of the resistors. It will be noted that as the nominal resistance increases or as the temperature of the environment decreases, the resistance ratio becomes greater. In addition, increased power dissipation tends to decrease the resistance ratio. Within experimental error the semi-log plots appear as straight lines.

With the help of these graphs it becomes a simple matter to determine the expected magnitude of the resistance in liquid once the following are known: (1) the maximum allowable power dissipation, (2) the nominal rating of the selected resistor, and (3) the liquid to be detected.

5. Relative Precision And Reliability of Resistors

The precision of a number of liquid level sensors was determined

in separate tests conducted at the Cryogenic Engineering Laboratory[1]. The sensors were lowered into a liquid hydrogen bath until a wet indication was noted and then raised until a dry indication was observed, the distance traveled being measured to the nearest .001 inch. From these data a bandwidth denoting the maximum distance between the wet and dry indications for any given sensor was produced. In order to determine how pressurizing the liquid affects the magnitude of the bandwidth, a series of runs were conducted on each sensor at pressures ranging from two to 200 psig.

Among the commercial liquid level indicators evaluated in this manner was a 0.1 watt, 1000 ohm carbon resistor type, (manufactured by Ohmite), which was positioned with its major axis parallel to the liquid-vapor interface. The bandwidth was found to vary from 0.015 to 0.122 inch. Bandwidths varying from 0.020 to 0.028 inch were found for a hot wire sensor similarly tested. No simple correlation was found between pressure and bandwidth.

Response time, determined in the same test program, was found to vary from 0.003 to 1.128 seconds for the hot wire sensor, while the response time of resistors in the present program (see Discussion of Results and figures 4 through 12) ranges from about 0.5 to 8.0 seconds.

Although reliability tests were not included in either program, resistors have been frequently used for liquid level sensors at the Cryogenic Engineering Laboratory, and it has been found that their characteristics vary at times. Prolonged thermal cycling, for example,

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[1] D. A. Burgeson, W. G. Pestalozzi, and R. J. Richards, "The Performance Of Point Level Sensors In Hydrogen," Advances in Cryogenic Engineering 9, In Press.

has been known to cause resistance changes of as much as 10%, but this can be corrected by a minor circuit adjustment.

In general, the resistor leads should be cut as short as possible to reduce the effective mass, care should be taken when attaching the lead-out wires because heating can increase the resistance by as much as 10%, and the probe design should provide for liquid drainage away from the resistor.

6. Conclusion

The results of the test program show that the time response of resistors is somewhat slower than that of a hot wire sensor. Sensitivity depends upon the allowable power dissipation and the temperature of the liquid being detected, greater sensitivity being obtained when the power is increased or when the temperature of the liquid is decreased. The value of the resistance in liquid depends upon (1) the power dissipation, (2) the ohmic rating of the resistor, and (3) the liquid. Once these three parameters have been selected, the magnitude of the resistance in liquid may be readily determined.

The bandwidth of 1/8 inch for a horizontally mounted resistor is adequate for all but the most precise requirements. Resistors are inexpensive and easy to mount and the associated electrical circuitry can be simple.

It is apparent that ordinary carbon composition resistors perform reasonably well as liquid level sensors, and within the indicated limits, they are well suited for this purpose.

7. Appendix

The bridge components (see figure 15-a) are governed by the following considerations: the power dissipation of the ratio arms should

be a reasonable value, the resistance ratio R_L/R_A should be approximately equal to R_B/R_C, and the resistances of R_B and R_C should be small in relation to the amplifier's input impedance in order that high sensitivity may be obtained.

The design of a practical liquid level indicator will now be considered. Arbitrarily selected parameters are:

(1) maximum allowable power dissipation: 125 milliwatts or less

(2) liquid to be detected: hydrogen

(3) desired time response: two seconds or less.

Readily available components are:

(1) power supply: 26.5 volt, D. C., 600 ma

(2) indicator: 6 volt, 150 ma, #47 lightbulb

(3) amplifier: two-stage, transistorized, $Z \approx 5000$ ohms

(4) balancing potentiometer: 1000 ohm, 2 watt.

Figure 9 shows that a 1000 ohm, 0.5 watt resistor dissipating 115m watts satisfies the above criteria, and figure 14 shows that a resistor of this nominal rating will have a resistance ratio R_L/R_O of about 2.50. The resistance of R_L is then found to be approximately 2500 ohms. When half the resistance of the potentiometer (design null) is added to the resistance of R_L, the resistance between points "a" and "d" on figure 15-a is 3000 ohms.

In order to find suitable resistance values for the other three arms of the bridge, it is convenient to first find the current in the branch adc. Since 115 milliwatts are dissipated in R_L,

$$I_{adc} = \sqrt{\frac{115 \text{ mw}}{2500 \text{ ohm}}} = 6.78 \text{ ma, and}$$

$$R_{adc} = \frac{26.5 \text{ v}}{6.78 \text{ ma}} = 3900 \text{ ohm.}$$

This leaves 400 ohms for resistor R_A. A 0.5 watt, 390 ohm resistor (the nearest nominal resistance rating) is therefore selected. The resistance ratio of the two adjacent arms then becomes

$$R_{ad} / R_{dc} = 3000/890$$

$$= 3.37.$$

Recalling that high sensitivity will be obtained when the resistance of resistors R_B and R_C are small compared to the input impedance of the amplifier, a 300 ohm resistor is arbitrarily selected for R_B. The resistance of R_C is then calculated from the relation

$$R_B/R_C = R_{ad} / R_{dc}$$

or

$$R_C = 300/3.37$$

$$= 89 \text{ ohms}.$$

A 91 ohm resistor is therefore selected for R_C.

It remains to be determined whether or not these resistors will produce a reasonable power dissipation. The current in this portion of the circuit will be

$$I_{abc} = \frac{26.5 \text{ volts}}{391 \text{ ohms}}$$

$$= 68 \text{ ma}.$$

With this current, R_B will dissipate 1.39 watts, which is somewhat high. This indicates that larger resistors should be used to reduce I_{abc}. If

R_B is 1000 ohms, R_C will be about 300 ohms and the power dissipated in the larger resistor will be 0.4 watt. This is below the power rating for the resistor and R_{abc} is still low when compared with the input impedance of the amplifier.

The resistors finally selected for the bridge are

R_S: 1000 ohm, 0.5 watt

R_A: 390 ohm, 0.5 watt

R_B: 1000 ohm, 0.5 watt

R_C: 300 ohm, 0.5 watt.

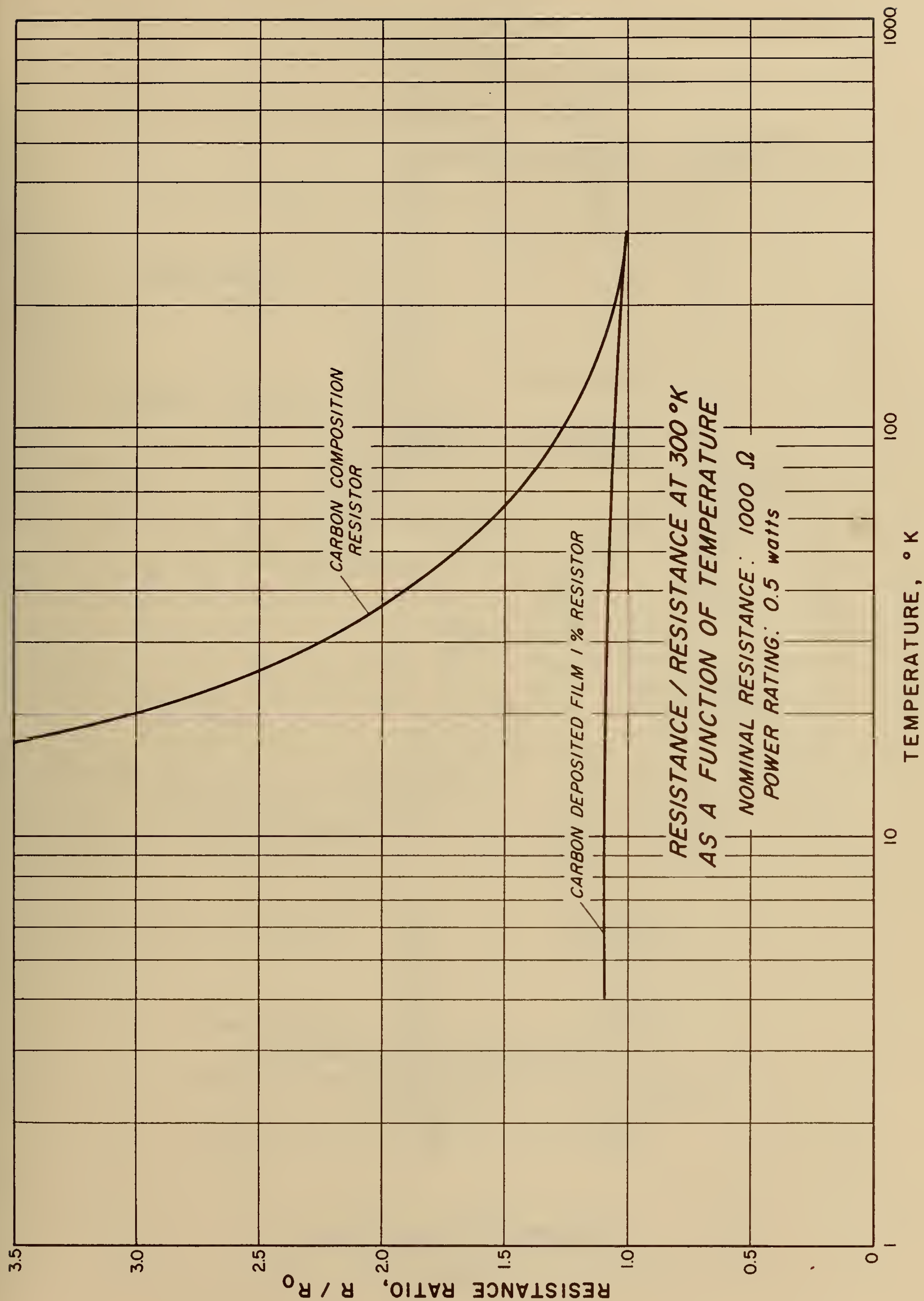
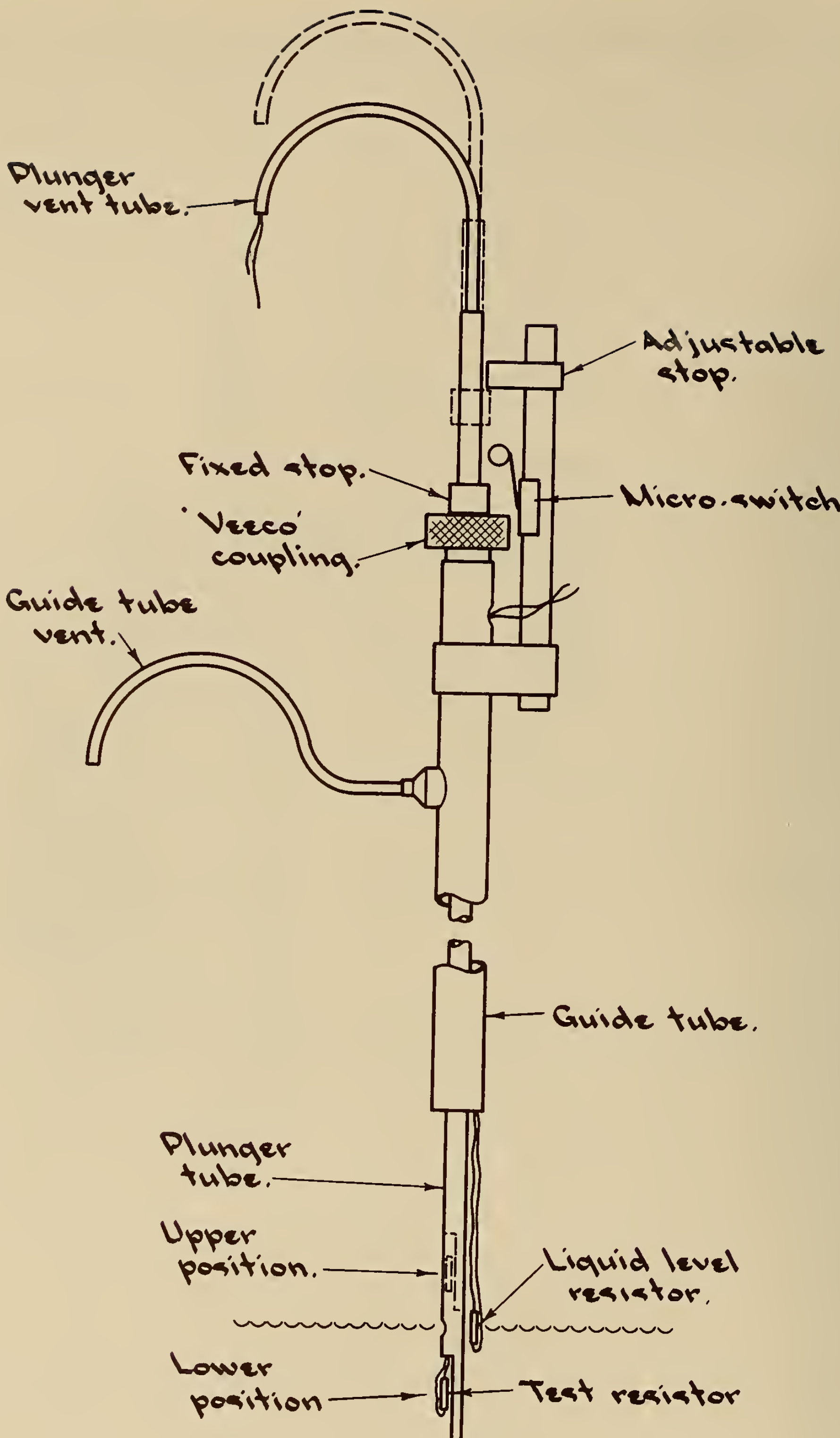
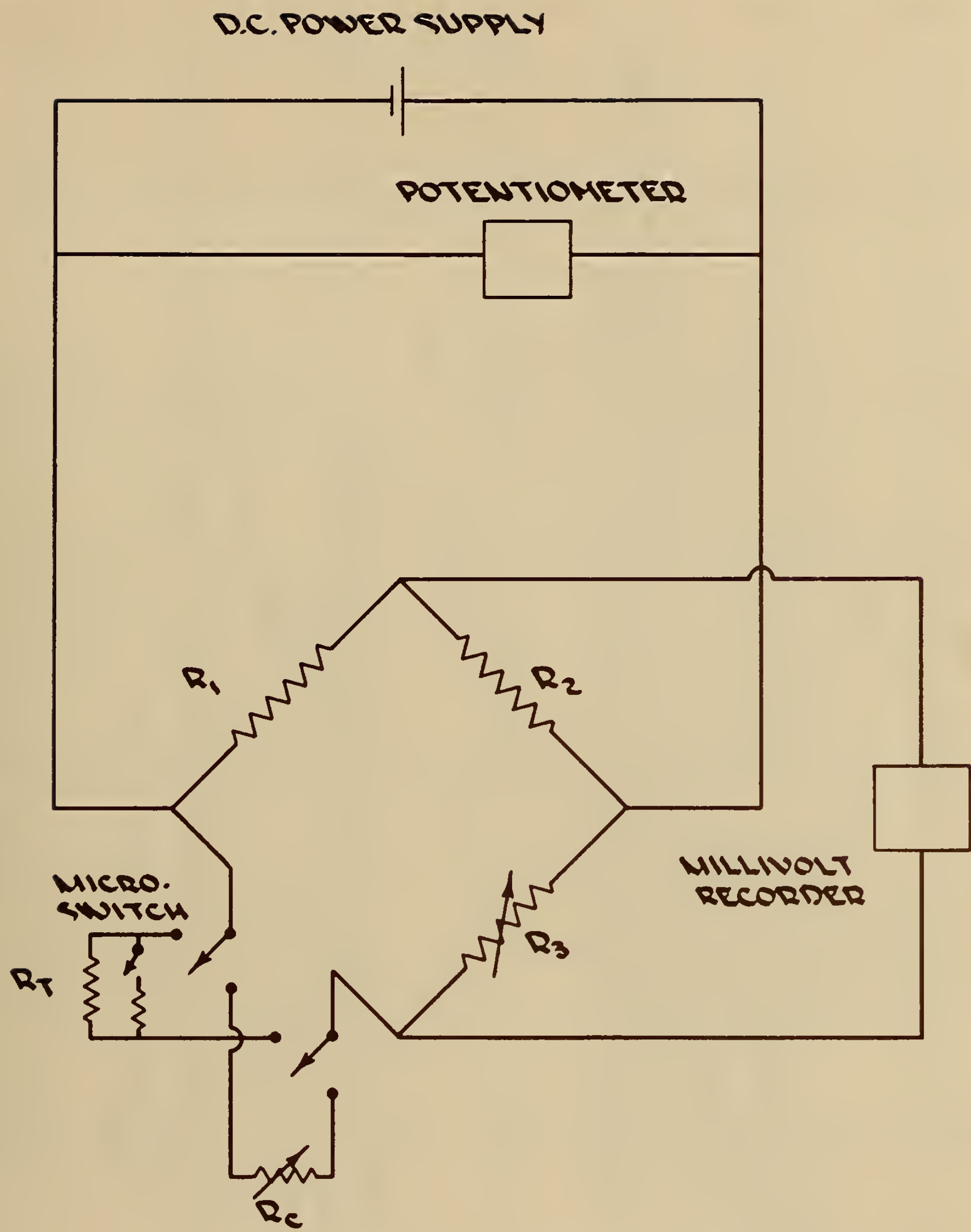

RESISTANCE / RESISTANCE AT 300 °K
AS A FUNCTION OF TEMPERATURE
NOMINAL RESISTANCE: 1000 Ω
POWER RATING: 0.5 watts
CARBON COMPOSITION RESISTOR
CARBON DEPOSITED FILM 1 % RESISTOR
RESISTANCE RATIO, R / R0
TEMPERATURE, °K
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
1
10
100
1000

Figure 1



PROBE ASSEMBLY

Figure 2



WIRING DIAGRAM OF
LIQUID LEVEL RESISTOR TESTS

Figure 3

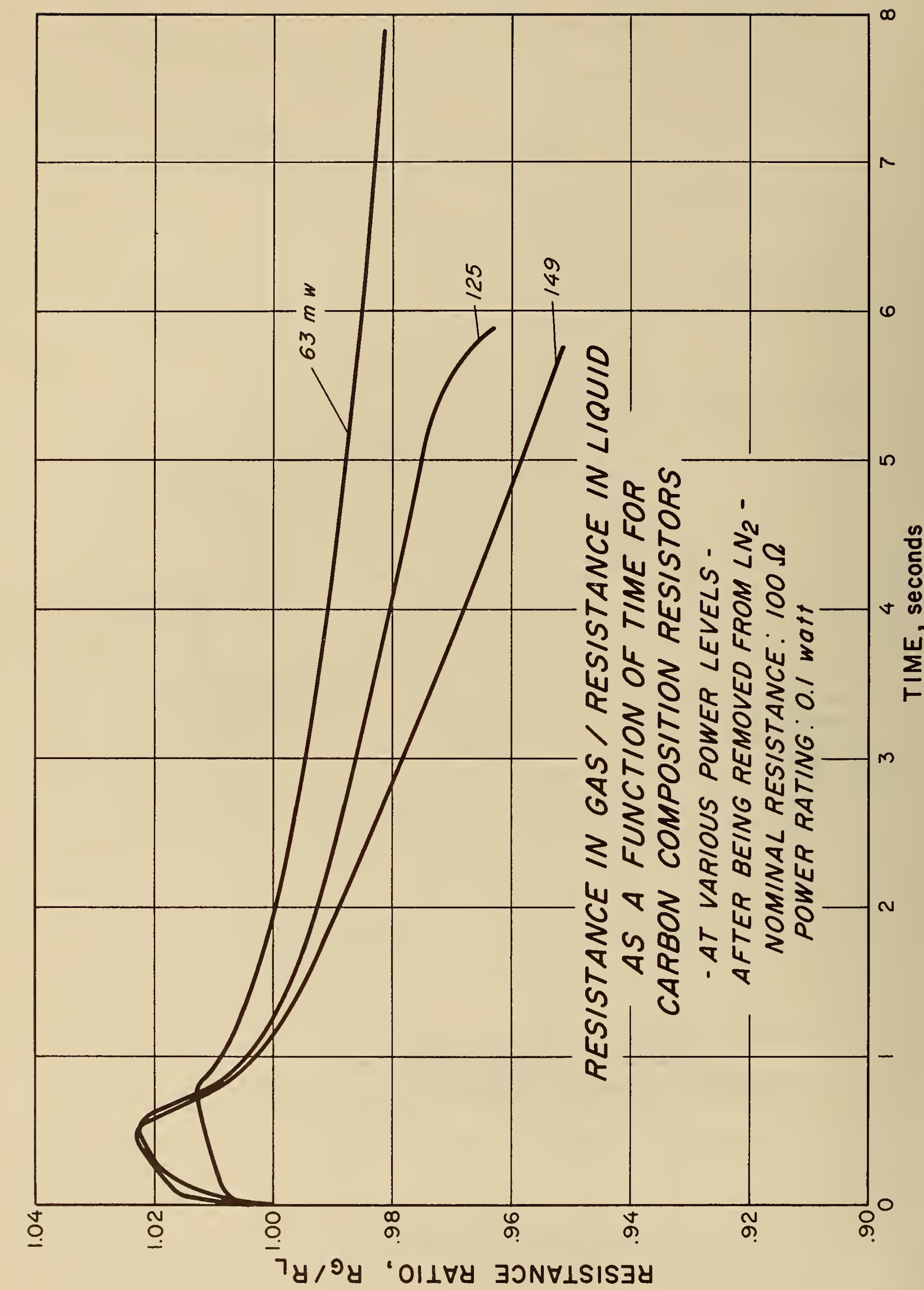

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LN_2 -
NOMINAL RESISTANCE: 100 Ω
POWER RATING: 0.1 watt
63 mw
125
149
RESISTANCE RATIO, R_G/R_L
1.04
1.02
1.00
.98
.96
.94
.92
.90
0
1
2
3
4
5
6
7
8
TIME, seconds

Figure 4

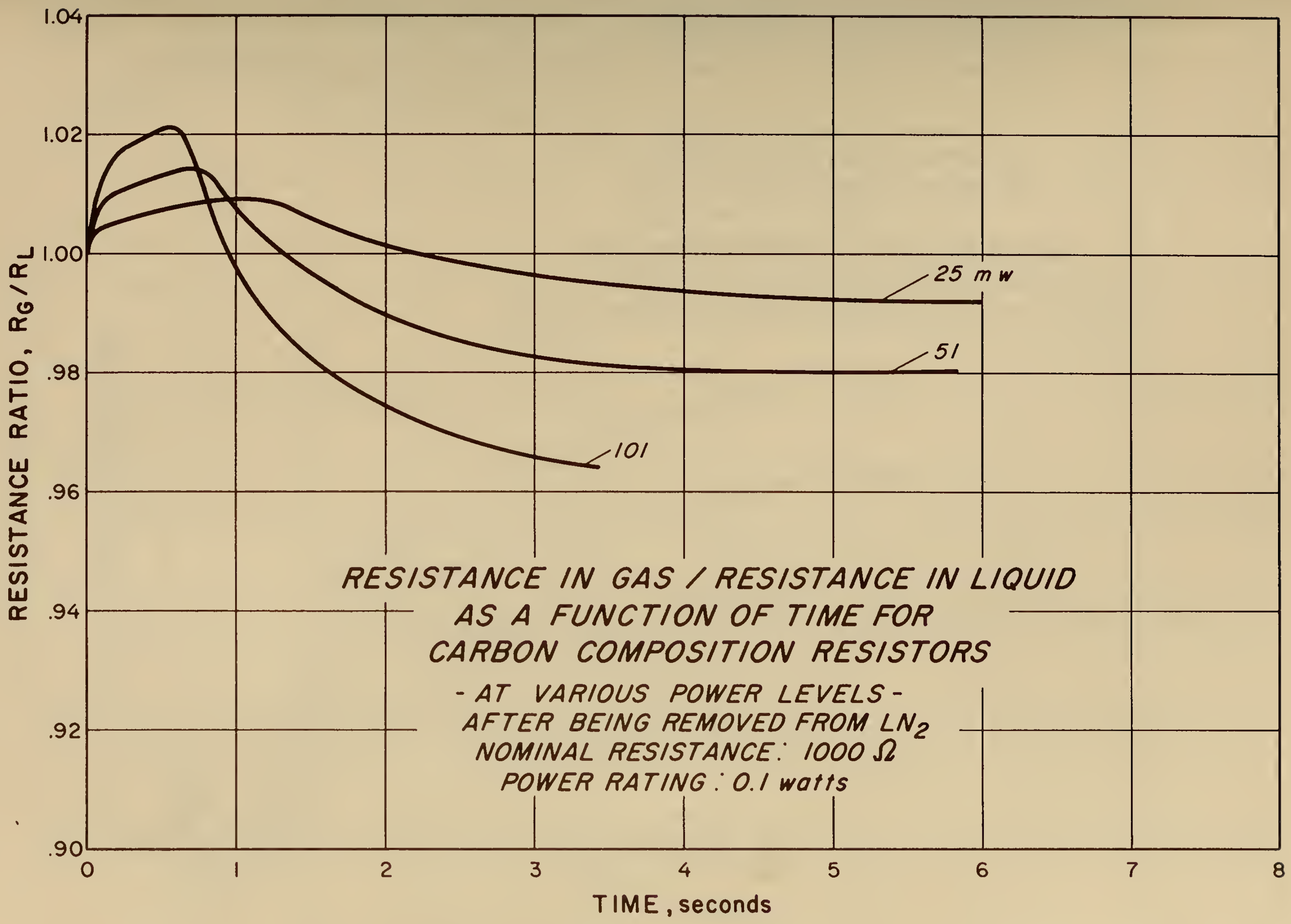

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LN_2
NOMINAL RESISTANCE: 1000 Ω
POWER RATING: 0.1 watts
25 mw
51
101
RESISTANCE RATIO, R_G/R_L
1.04
1.02
1.00
.98
.96
.94
.92
.90
0
1
2
3
4
5
6
7
8
TIME, seconds

Figure 5

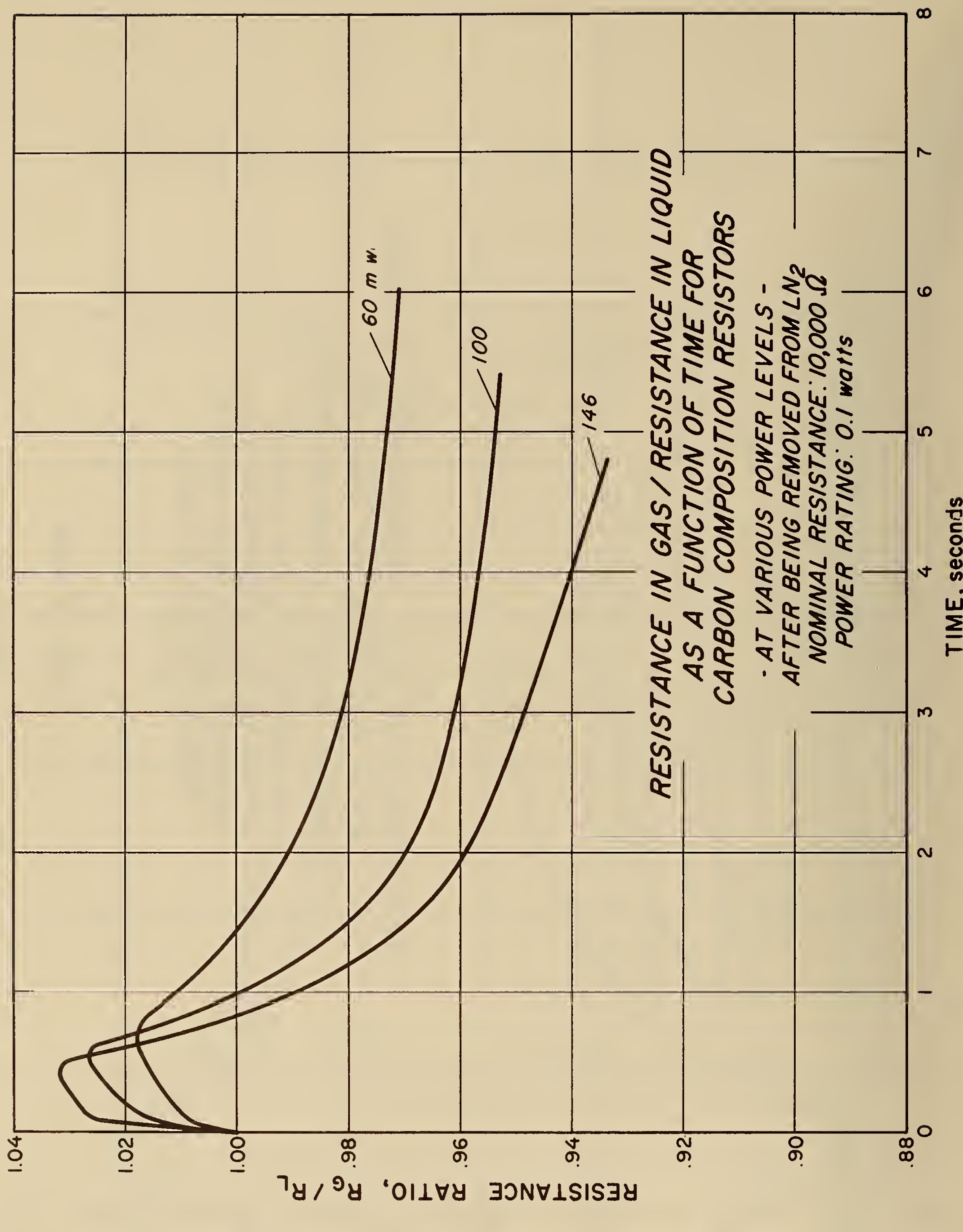
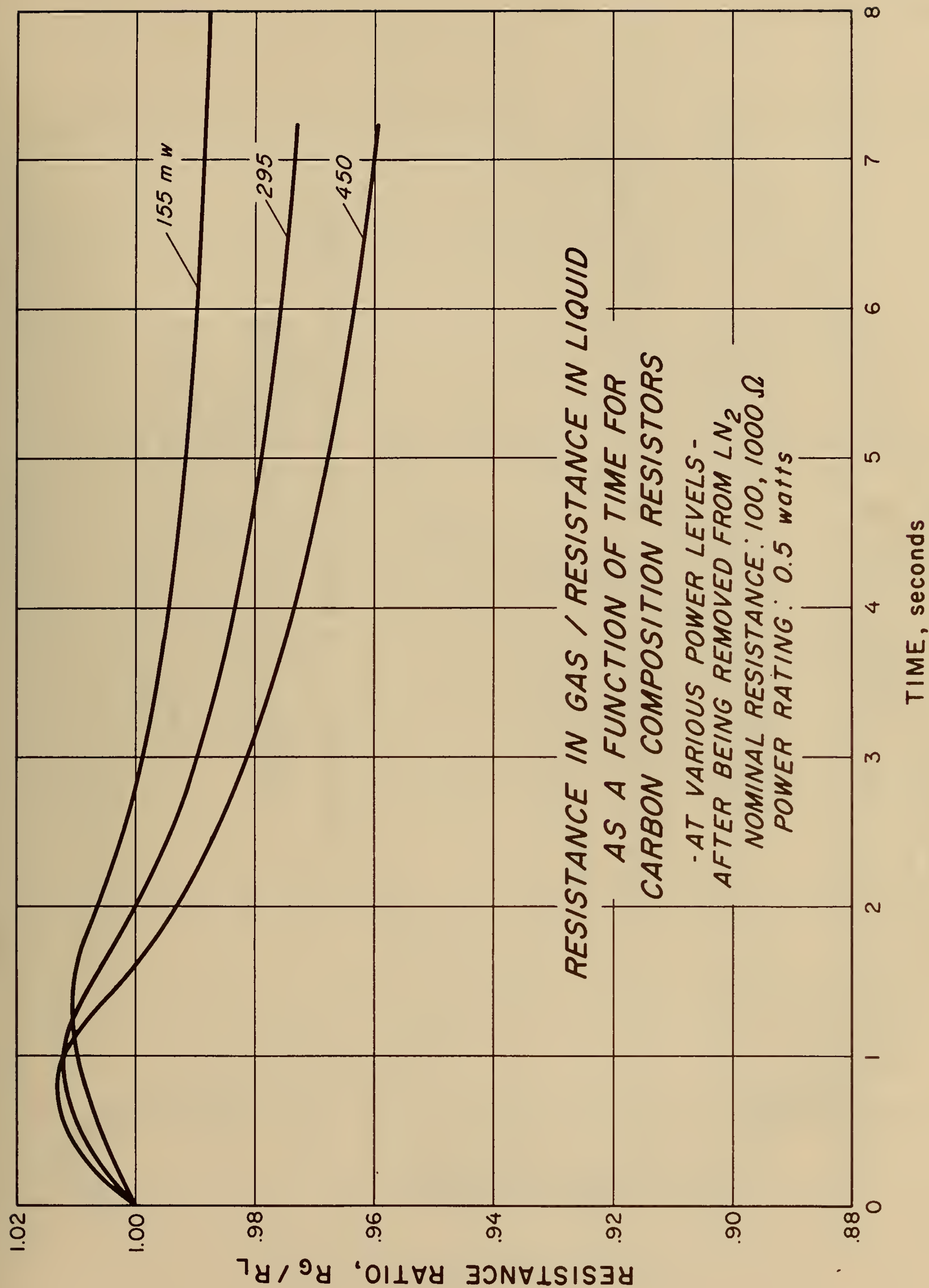

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LN_2
NOMINAL RESISTANCE: 10,000 Ω
POWER RATING: 0.1 watts
60 m w.
100
146
RESISTANCE RATIO, R_G / R_L
1.04
1.02
1.00
.98
.96
.94
.92
.90
.88
TIME, seconds
0
1
2
3
4
5
6
7
8

Figure 6



RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
-AT VARIOUS POWER LEVELS-
AFTER BEING REMOVED FROM LN_2
NOMINAL RESISTANCE: 100, 1000 Ω
POWER RATING: 0.5 watts
155 mw
295
450
RESISTANCE RATIO, R_G / R_L
1.02
1.00
.98
.96
.94
.92
.90
.88
TIME, seconds
0
1
2
3
4
5
6
7
8

Figure 7

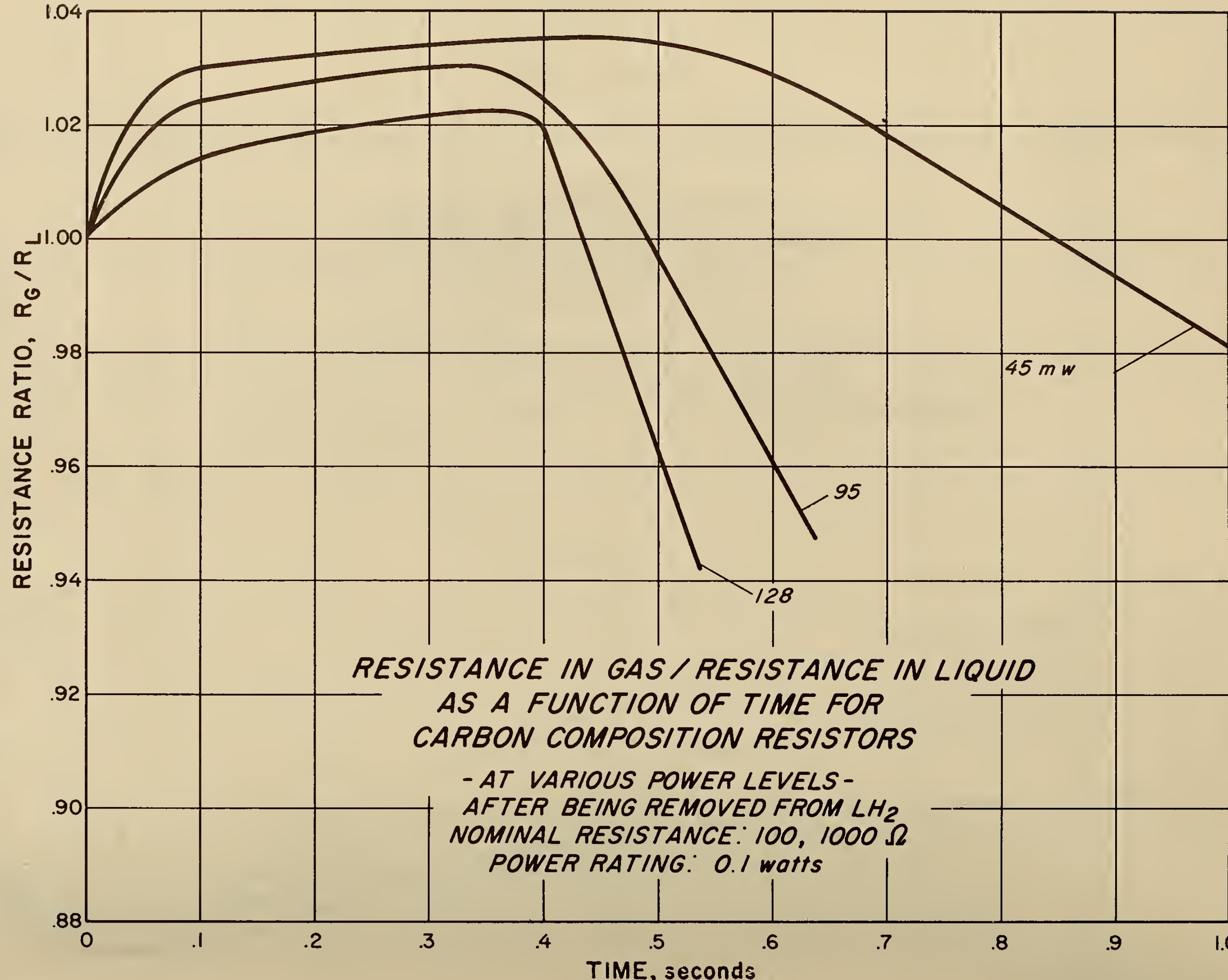

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LH2
NOMINAL RESISTANCE: 100, 1000 Ω
POWER RATING: 0.1 watts
45 mw
95
128
RESISTANCE RATIO, RG / RL
TIME, seconds
1.04
1.02
1.00
.98
.96
.94
.92
.90
.88
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

Figure 8

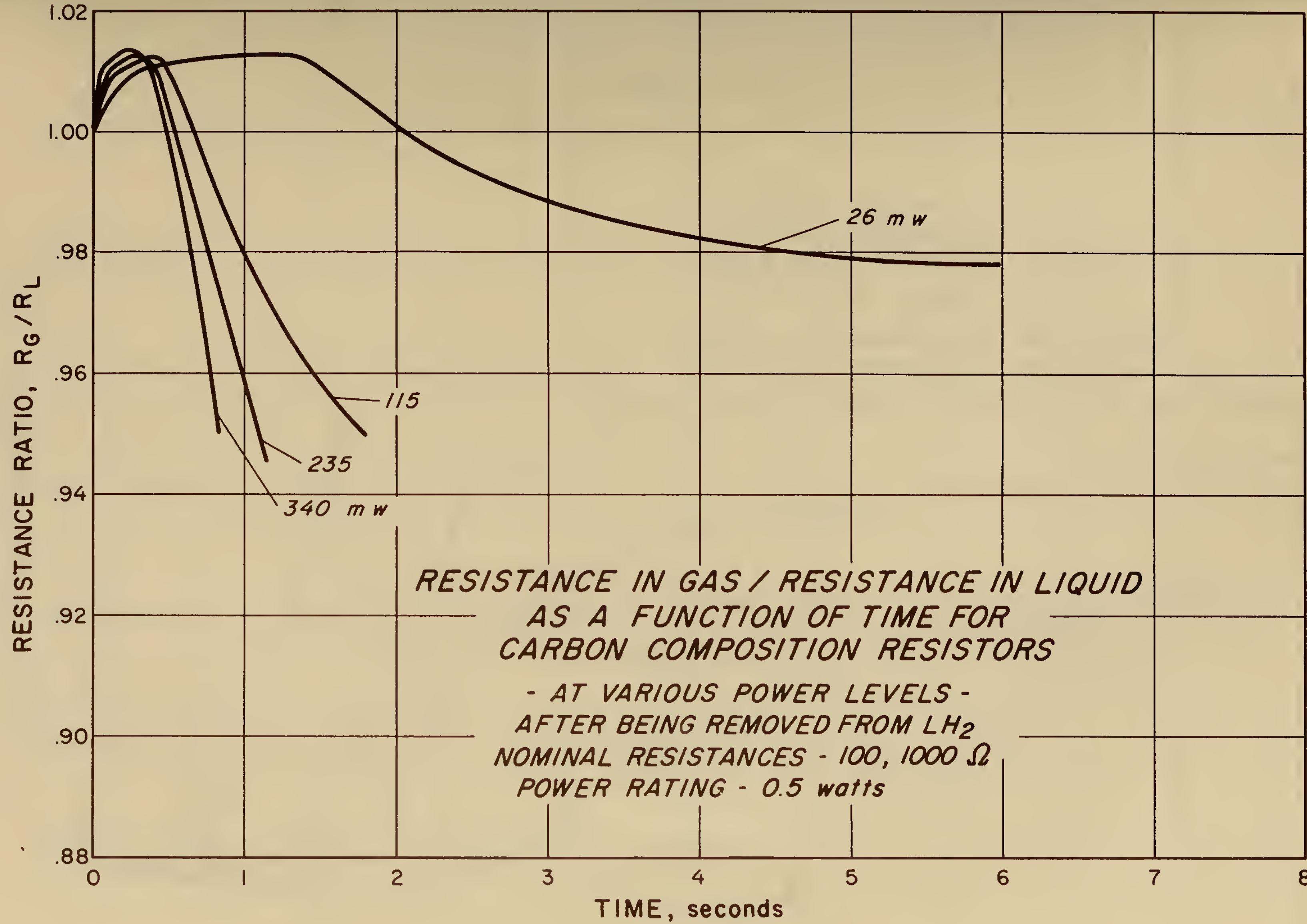

1.02
1.00
.98
.96
.94
.92
.90
.88
RESISTANCE RATIO, R_G / R_L
0
1
2
3
4
5
6
7
8
TIME, seconds
26 mw
115
235
340 mw
RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LH_2
NOMINAL RESISTANCES - 100, 1000 Ω
POWER RATING - 0.5 watts

Figure 9

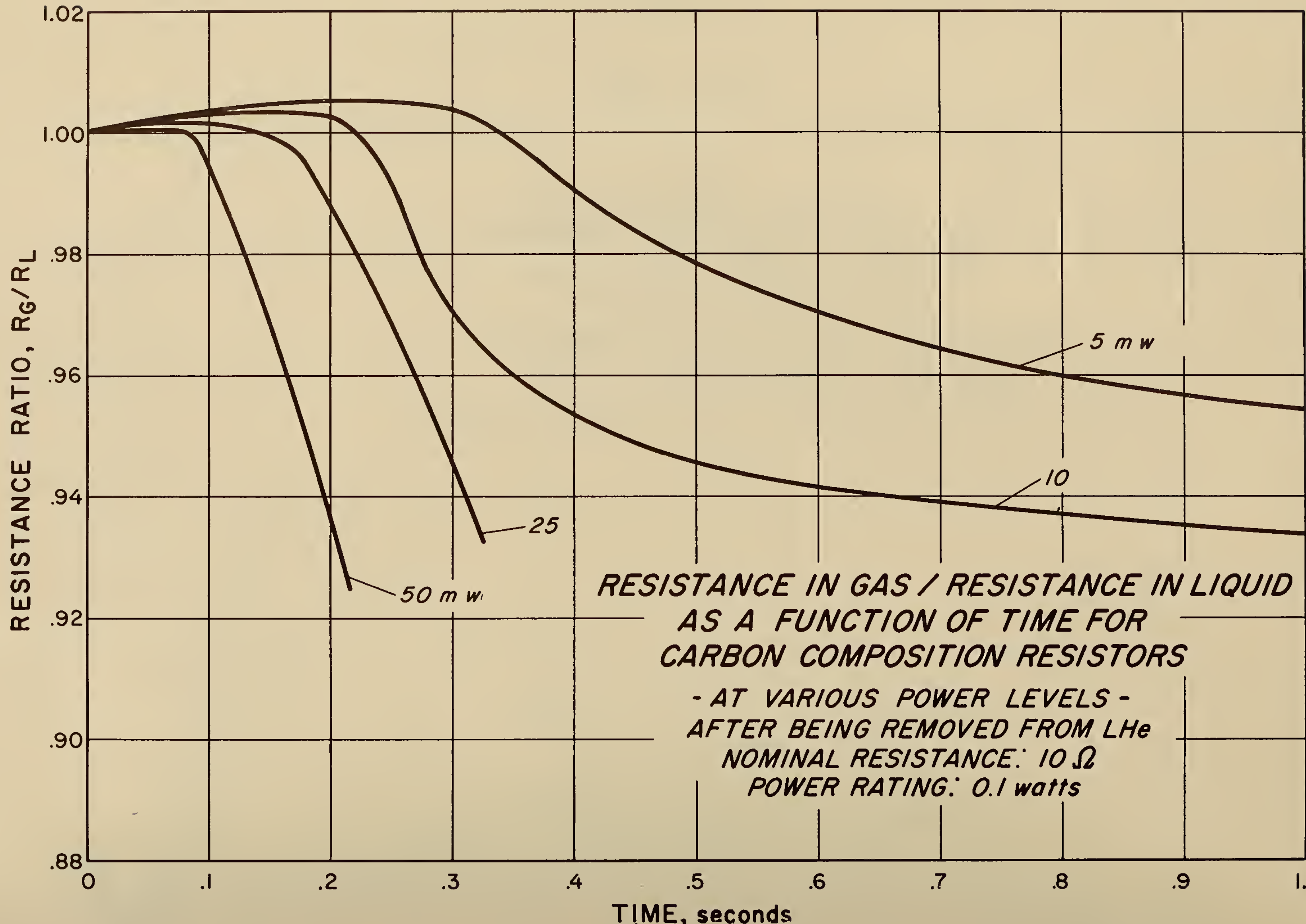

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LHe
NOMINAL RESISTANCE: 10 Ω
POWER RATING: 0.1 watts
5 m w
10
25
50 m w
RESISTANCE RATIO, R_G/R_L
TIME, seconds
1.02
1.00
.98
.96
.94
.92
.90
.88
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

Figure 10

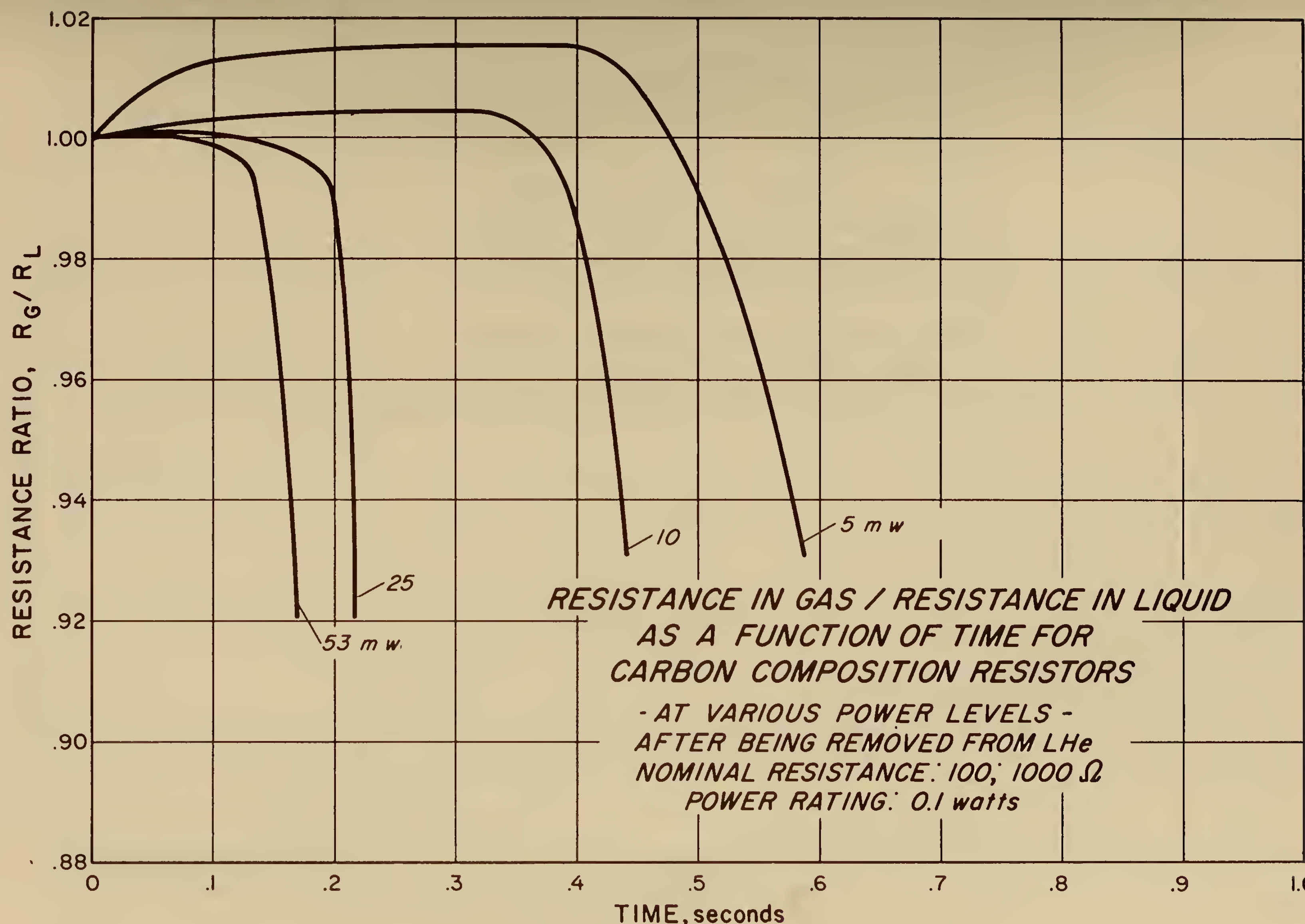

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LHe
NOMINAL RESISTANCE: 100; 1000 Ω
POWER RATING: 0.1 watts
RESISTANCE RATIO, R_G/R_L
TIME, seconds
5 m w
10
25
53 m w.
1.02
1.00
.98
.96
.94
.92
.90
.88
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

Figure 11

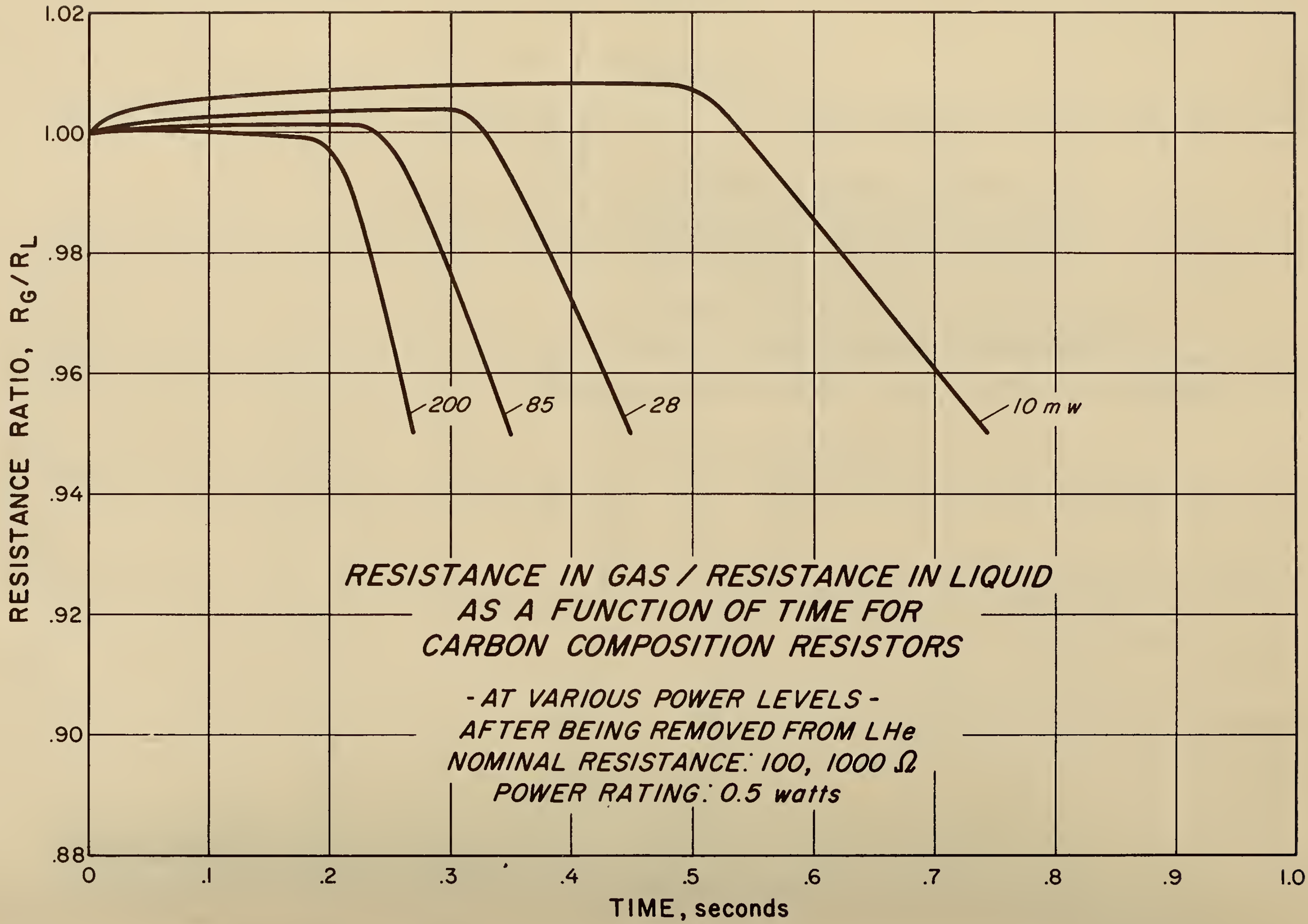

RESISTANCE IN GAS / RESISTANCE IN LIQUID
AS A FUNCTION OF TIME FOR
CARBON COMPOSITION RESISTORS
- AT VARIOUS POWER LEVELS -
AFTER BEING REMOVED FROM LHe
NOMINAL RESISTANCE: 100, 1000 Ω
POWER RATING: 0.5 watts
200
85
28
10 mw
RESISTANCE RATIO, R_G/R_L
1.02
1.00
.98
.96
.94
.92
.90
.88
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
TIME, seconds

Figure 12

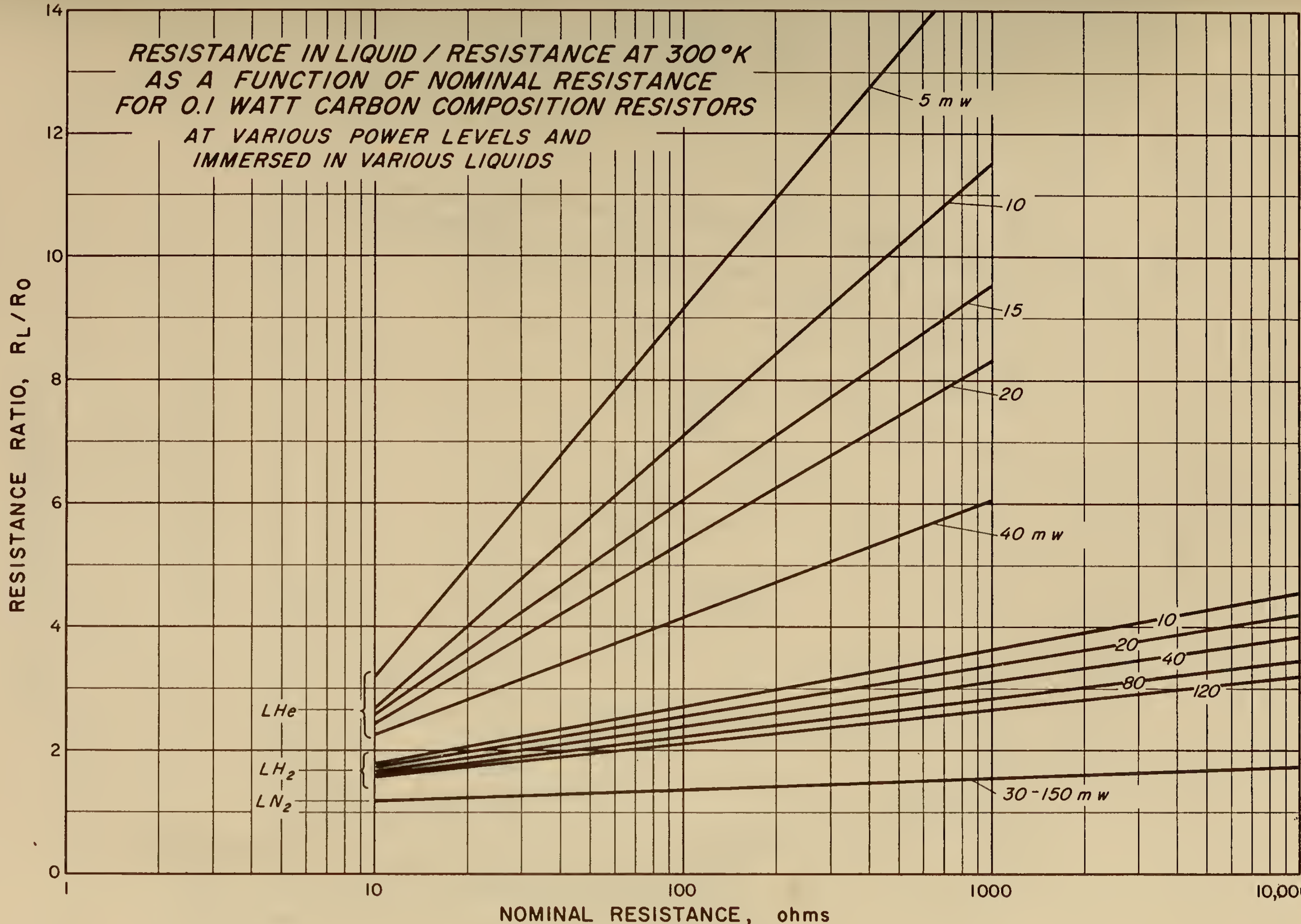
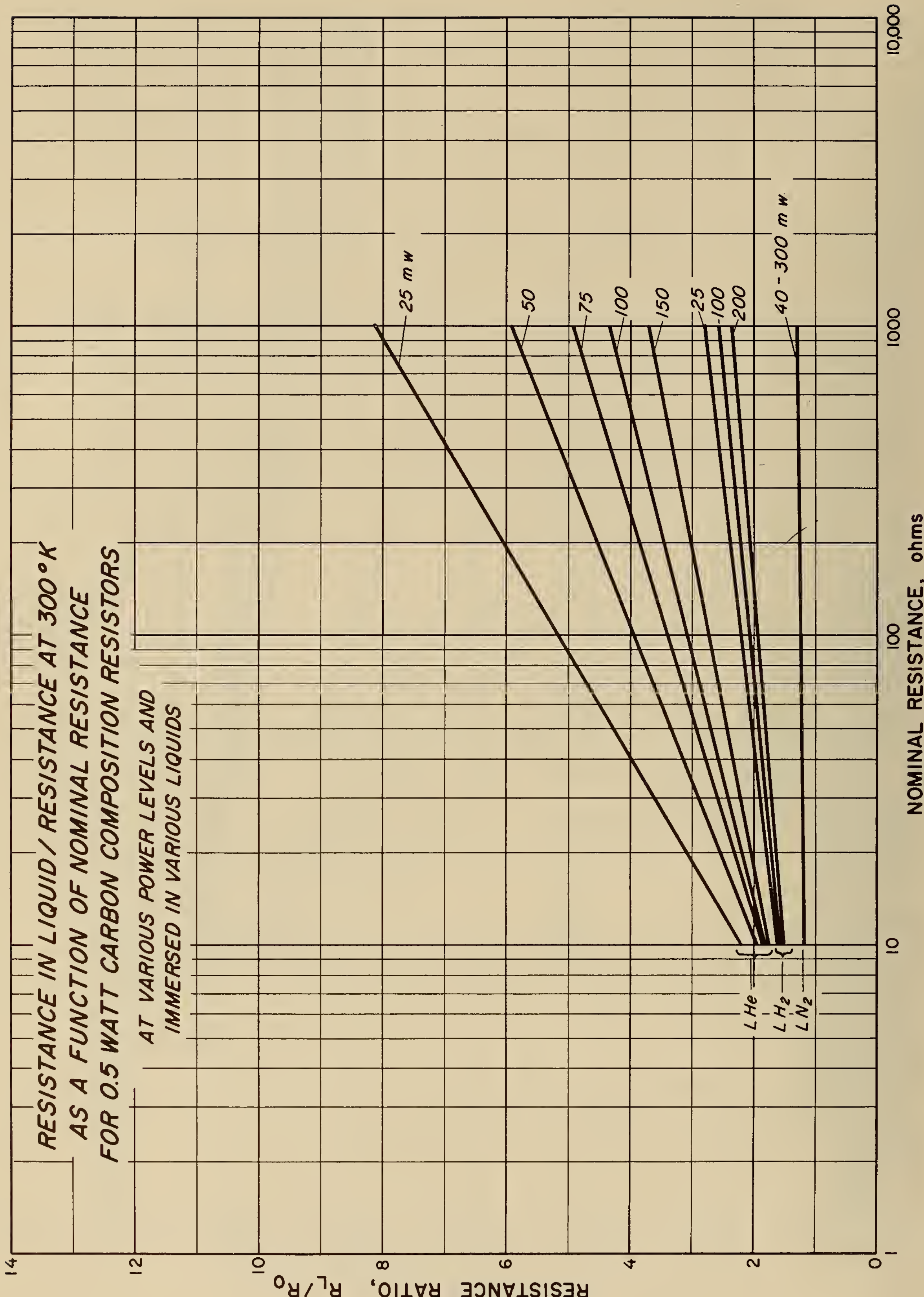
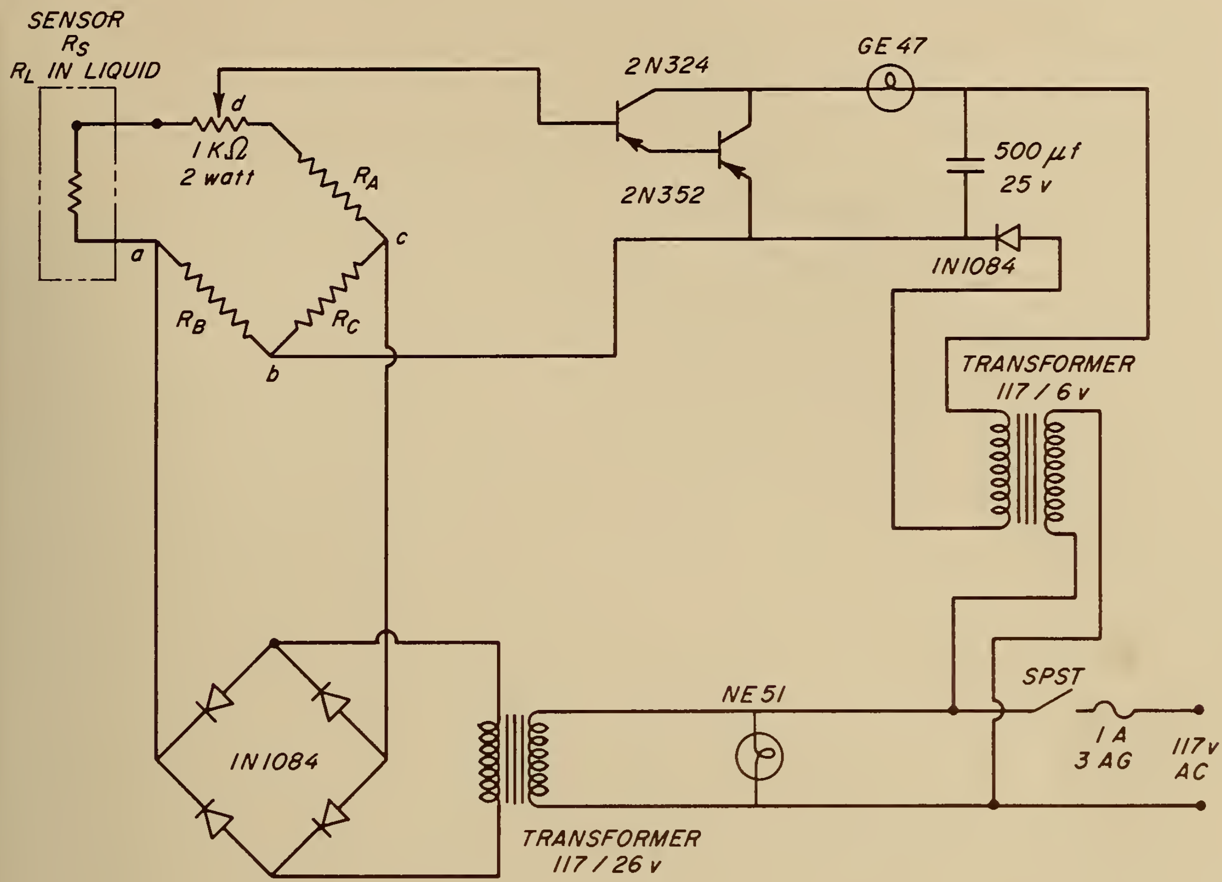

RESISTANCE IN LIQUID / RESISTANCE AT 300°K
AS A FUNCTION OF NOMINAL RESISTANCE
FOR 0.1 WATT CARBON COMPOSITION RESISTORS
AT VARIOUS POWER LEVELS AND
IMMERSED IN VARIOUS LIQUIDS
RESISTANCE RATIO, R_L/R_0
NOMINAL RESISTANCE, ohms
0
2
4
6
8
10
12
14
1
10
100
1000
10,000
5 m w
10
15
20
40 m w
10
20
40
80
120
30-150 m w
LHe
LH_2
LN_2

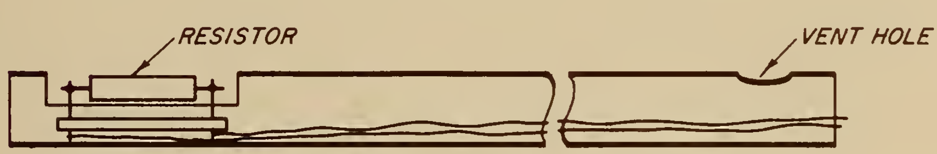
Figure 13


RESISTANCE IN LIQUID / RESISTANCE AT 300°K
AS A FUNCTION OF NOMINAL RESISTANCE
FOR 0.5 WATT CARBON COMPOSITION RESISTORS
AT VARIOUS POWER LEVELS AND
IMMERSED IN VARIOUS LIQUIDS
25 mw
50
75
100
150
25
100
200
40 - 300 mw
L He
L H2
L N2
RESISTANCE RATIO, RL/Ro
NOMINAL RESISTANCE, ohms
0
2
4
6
8
10
12
14
1
10
100
1000
10,000
Figure 14



SCHEMATIC OF A LIQUID LEVEL INDICATOR

Figure 15-a



PROBE ASSEMBLY

Figure 15-b

GPO 836-534

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage. Absolute Electrical Measurements.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY

Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

Radio Standards Engineering. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

Joint Institute for Laboratory Astrophysics-NBS Group (Univ. of Colo.).

NBS